USAARL Report No. 2011-19

The Effects of Subthreshold Visual Cues on Flight Performance in the NUH-60FS Black Hawk Research Simulator

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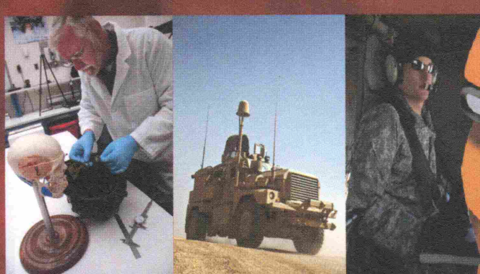

United States Army Aeromedical Research Laboratory

Warfighter Health Division

August 2011

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01-08-2011	Final	

4. TITLE AND SUBTITLE
The Effects of Subthreshold Visual Cues on Flight Performance in the NUH-60FS Black Hawk Research Simulator

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jeremy Athy
Arthur Estrada
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, AL 36362

8. PERFORMING ORGANIZATION REPORT NUMBER
USAARL 2011-19

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
504 Scott Street
Fort Detrick, MD 21702

10. SPONSOR/MONITOR'S ACRONYM(S)
USAMRMC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Pilots work in one of the most cognitively demanding environments. While technology continues to advance with respect to quantity and quality of information presentation, the human visual system remains with limitations and thus information processing may become more complex for pilots. Therefore, it is important to find improved techniques for information presentation in the cockpit without sacrificing overall flight performance. One potentially useful form of presentation is subthreshold cueing. This study required pilots to fly a mission in the UH-60 simulator while presented with subthreshold cues on a multifunction display. Results suggest that pilots were able to process subthreshold cues without compromising flight performance.

15. SUBJECT TERMS
attention, cognitive load, visual processing

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UNCLAS	UNCLAS	UNCLAS	SAR	32	Loraine St. Onge, PhD

19b. TELEPHONE NUMBER *(Include area code)*
334-255-6906

Reset

Acknowledgements

The authors would like to express their gratitude to the following individuals for their contributions to this study:

- Kate Hewett for writing the initial protocol for this research project.
- Victor Estes and Dennis Bergstrazer for their involvement as research pilots.
- Kevin Baugher and Jeffrey Holemo for setting up the UH-60 simulator and creating the multifunction display used in this study.
- Paul Strickland and Charles Brown for their expertise and programming of the UH-60 simulator.

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Introduction

The cockpit environment provides pilots with an essentially limitless amount of information, but the amount of information that a pilot can process at any given moment is extremely limited. The human brain cannot process all of the visual information available within the environment. Therefore, one must decide what information is meaningful and what is meaningless. For pilots, meaningful information includes recognizing changes within the environment as they occur. Despite the lack of aspect (the area outside of the central fovea region), the visual system has developed so that the peripherals of vision excel in motion detection and the registration of a new light source, two cues highly associated with a change in the environment. However, in order to determine what has caused these changes within the environment, attention typically must be shifted to the new location.

Subthreshold priming

The seminal work of Greenwald, Draine, and Abrams (1996) demonstrated subthreshold activation of meaning via ultra-short masked stimuli. They found that participants did not consciously process the prime word (i.e., X) when presented for 50 milliseconds (ms) or faster, which was followed by a mask. However, despite a lack of conscious recognition, the presentation did demonstrate priming or interference for the task. Later studies further indicated examples of successful demonstrations of subthreshold priming and evidence of mental activity without conscious awareness (Bernat, Shevrin, & Snodgrass, 2001; Draine & Greenwald, 1998; Seiss & Praamstra, 2004; see Kouider & Dupoux, 2004 for a counter example) with stimuli ranging from number comparison tasks (e.g., Naccache & Dehaene, 2001), arrows determining directional responses (e.g., Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003), and facial expressions (Esteves, Dimberg, & Öhman, 1994). One study even showed the effects of the prime to last for an extended period of 15 minutes (Bar & Biederman, 1998). However, without exception, each study cited above was conducted under very controlled/sterile conditions.

Subthreshold priming research remains controversial for a number of reasons; namely, the aforementioned controlled conditions, statistically weak findings, inability to replicate findings, and scarcity of published replications. More importantly, there is an absence of research in the literature regarding the actual *application* of this effect. However, the debate tends to accept the general premise that subthreshold priming can, under certain conditions and circumstances, provoke an unconscious cognitive response. Even so, there is much controversy surrounding the internal and external validity of experimental designs, methods, measures, and findings that indicate causation.

Military relevance

One of the most visually taxing environments found today exists in the cockpit (figure 1). Today’s pilots are required to scan various displays in order to update information on flying status while also taking time to gather information from the real world outside of the cockpit. Having the combination of both internal and external information is necessary for the pilot to maintain situational awareness (SA). A loss of SA is described as the condition when an

individual has not taken into account information concerning his or her environment and this loss of alertness can lead to catastrophic results. In fact, this loss of SA contributes to many aviation accidents every year (Endsley, 1995).

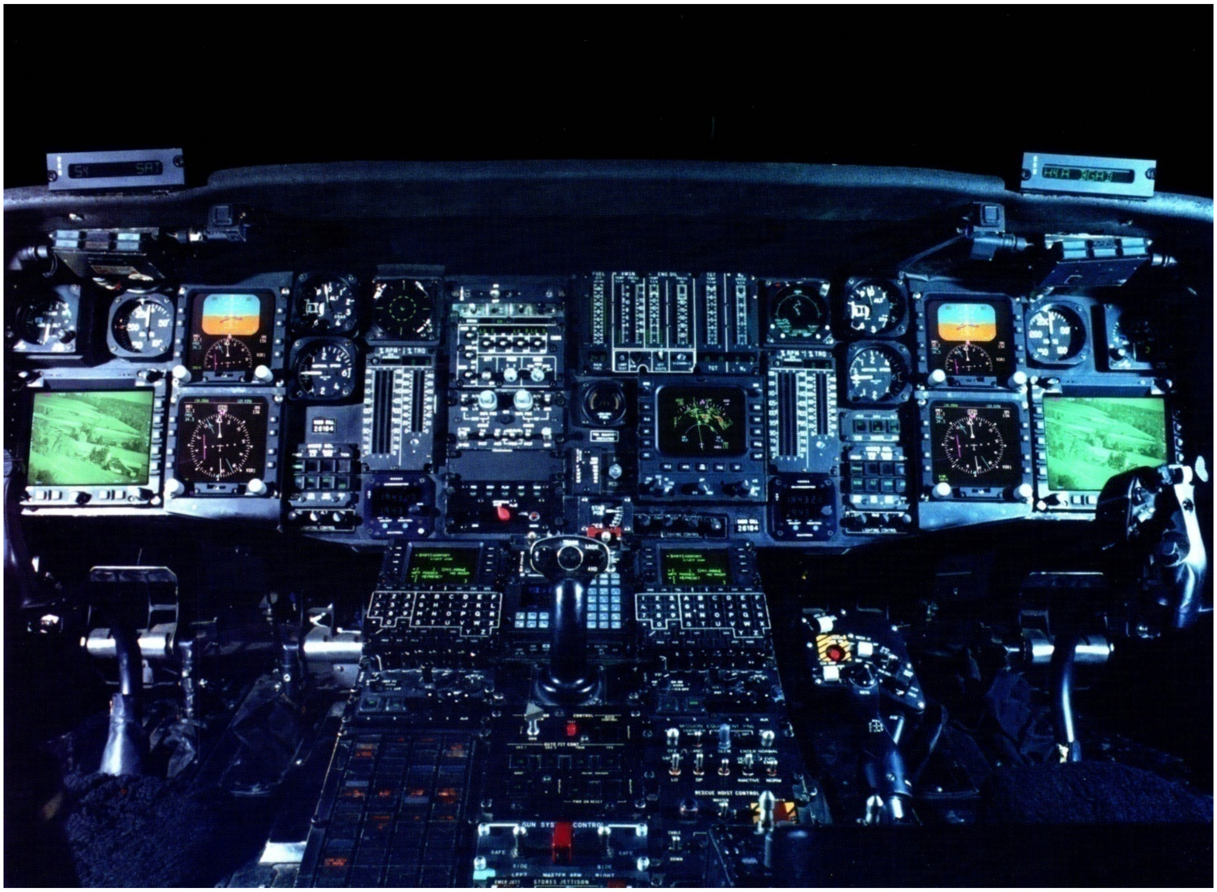

Figure 1. Multifunction displays in the cockpit of an MH-60L.

Aircraft cockpit flight and systems instrumentation technology has advanced from dials and lighted-strip, single-function instruments to visually demanding multifunctional displays (MFD) in order to improve pilot performance. These displays present substantial amounts of complex data on a single screen. The pilot's visual workload can become taxed and result in the challenging exercise of cognitively processing and maintaining an awareness of all the information presented. This visual overload of information can result in the exclusion of other important information presented in the peripherals or external to the MFD as the pilot attempts to process the information provided by the MFD. Given this, it is important to determine alternate delivery methods of visual information to the pilot.

Typical visual alarms or notifications found in the periphery take advantage of how the visual system works. As previously stated, the visual system, even in the periphery where attention is not focused, is very effective at detecting changes (e.g., the introduction of new information) in the environment. However, the natural response to these newly detected environmental stimuli

is to focus attention away from the current area toward the new stimuli. This process is ideal for a situation that demands a pilot's immediate attention (e.g., a situation concerning an imminent danger that must handled immediately), but at other times may distract the pilot from a more important task.

It would appear that pilots would benefit from a presentation of non-critical information in ways that did not capture or distract their attention from the current task. As previously discussed, researchers have suggested that subthreshold priming allows unconscious processing of visual information which can influence cognitive processes. The current study attempted to identify whether or not subthreshold processing could be utilized to present information to a pilot during times of high cognitive load and thus allow information to be processed without taking attention away from current demands.

A recent study by Hewett, Estrada, Rath, Cruz, and Kelley (2009) set out to determine the applicability of subthreshold priming in a real-world situation. Twelve helicopter pilots flew an hour-long mission on the Microsim flight simulator at the U.S. Army Aeromedical Research Laboratory (USAARL). The study required the pilots to check a separate monitor for updated flight maneuvers which would direct the pilot to a new task. The separate monitor consisted of a numeric display placed on top of the simulated controls. This numeric display presented the numbers 0 to 9 for 500 ms each with a blank 50 ms inter-stimulus interval (ISI) throughout the entire flight. These numbers were used as masks for a subthreshold presentation of the letter "E". When pilots detected the letter during the flight, they were to check a covered monitor for status changes and change their flight accordingly. The study found that pilots processed the information concerning the subthreshold cueing at a mean response time of 31.35 seconds (SD = 29.8 seconds) with only 13 of the 96 subthreshold presentations (which lasted a maximum of 120 seconds) not detected (13.54%).

In Hewett et al. (2009), presentation of subthreshold cues to pilots deviated from how previous research presented subthreshold cues. In most subthreshold studies, the participant is required to be staring directly where the subthreshold cue is to be presented. A pilot though is typically tasked with maintaining a scanning behavior, where they are constantly shifting attention from one area to another. This scanning is similar to the behavior found in driving where one does not simply look forward at all times but regularly looks into the side and rear view mirrors and at the speed gauge in order to maintain SA. Scanning however creates a unique problem with presenting subthreshold information in that the pilot may not be looking at the monitor presenting the subthreshold cues during a subthreshold presentation. In order to account for this, Hewett et al. (2009) replaced the single subthreshold presentation with repeating presentations of the letter "E" (the subthreshold cue). This created a scenario in which pilots had a 2-minute window to detect a subthreshold cue and respond to it, while maintaining their typical scanning behavior. This introduced a scenario in which pilots were exposed to the subthreshold cue multiple times, a situation unlike previous studies.

Objectives

Hewett et al. (2009) introduced a procedure to incorporate subthreshold cues into a pilot's scanning behavior in order to present information. However, this procedure involved no

reduction of cognitive resources for the pilot due to requiring an additional item to be scanned. The current study attempted to create a form of subthreshold presentation that did not require pilots to engage in a new scanning behavior, but rather, presented visual information in a format already within the pilot's scan. This was accomplished by presenting 16-ms visual cues via MFD. The MFD is already a critical component of a pilot's scanning behavior, so a new scanning behavior did not need to be utilized. This process tested if pilots could be presented brief subthreshold visual information while observing the information presented on the MFD. If the pilots processed this visual information at a subthreshold level it would suggest further research into the limits of subthreshold processing and how it could better assist a pilot's processing of information in the visual environment.

The primary goal of this experiment was to determine if pilots could process subthreshold presentations of visual information correctly within an acceptable time frame. If information was not correctly interpreted or was processed too slowly, then it was of no use for keeping the pilot situationally aware. This study required pilots to differentiate three letters as cues and measured the response reaction time. The secondary goal was to determine if the processing of this subthreshold information was detrimental to precision flight. If pilots were able to accurately process this information, yet demonstrated a cost in their flight performance, then the presentations were of no benefit to the pilot's performance. Finally, the tertiary goal of the study was to determine if performance in processing the visual information was affected over time. That is, did detection of the cues get better or worse as the pilots were exposed to additional cue presentations?

Methods

Subjects

Thirty subjects from the aviation community at Fort Rucker, AL, volunteered to participate in the study. The mean age of the subjects was 28.3 years (SD = 6.2 years, minimum = 22 years, maximum = 51 years) and included two females. All subjects were rated UH-60 pilots with a current "up" slip, indicating the pilot was in good health at the time of the study.

The demographics survey (appendix A) was used to determine the flight characteristics of our study population. Twenty-two of the pilots who participated in this study graduated from flight school during the year of the study, while the other eight pilots graduated within 4 to 16 years prior (table 1). Flight Activity Category (FAC) is designated by aviation commanders and is used to describe the proficiency of the pilot for particular jobs or positions, with FAC 1 indicating the greatest amount of flight activity and FAC 3 indicating the least flight activity. Many of our pilots could not report a FAC due to their recent graduation from flight school (n = 14, table 3). Readiness level (RL) indicates a pilot's proficiency to perform the unit's combat mission. An RL 1 indicates the highest degree of proficiency while an RL 3 has not yet demonstrated complete proficiency. Again, due to the recent graduation of many of our subjects, 20 reported having no RL (as indicated by an NA response) (table 3). Addition breakdowns of pilot ranks and job titles are provided in tables 2 and 4, respectively.

Table 1.
Frequency of reported years since graduation.

Years since graduation	0	4	5	6	9	14	26
Frequency	22	1	2	2	1	1	1

Table 2.
Frequency of pilot ranks.

Rank	CPT	1LT	CW5	CW4	W01
Frequency	8	5	1	1	15

Table 3.
Frequency of pilot FAC and RL.

	1	2	3	N/A
FAC Frequency	7	4	5	14
RL Frequency	3	0	7	20

Table 4.
Frequency of pilot job titles.

Job Title	Pilot in Command	Line Pilot	Instructor Pilot	Other
Frequency	3	23	2	2

Cue detection: Stimuli and apparatus

Flight simulator and flight details

USAARL's NUH-60FS Black Hawk simulator was used as the flight platform for this study. The full range of simulated motion was utilized and in-house software collected all flight data for each session at a rate of one sample every second. The simulated flight was composed of eight distinct flight waypoints to which the pilot flew while attempting to maintain specific headings, speeds, and altitudes above ground. When the aircraft approached within 0.2 miles of each waypoint, the research pilot selected the next destination for the flight and relayed the new flight information to the subject. At this time the technician stopped data collection until the subject finished the turn and headed toward the new waypoint.

The multifunction display

The standard UH-60 flight instrument display was covered by a panel that included an MFD created in-house (figure 2). The MFD presented the information that is typically found on the standard flight instrument display (figure 3) and allowed presentation of the subthreshold cues. The MFD had a refresh rate of approximately 16ms and subtended a visual angle of approximately 26° from the typical sitting distance of 26 inches. Due to the capabilities of the MFD, presentations of each subthreshold cue lasted approximately 16.4 ms as determined by Independent tests using a Tektronix TH5730A oscilloscope and 100 sample cue presentation on the MFD, with a max of 18.9 ms and a minimum of 14.7 ms. The average rise time of the stimuli was 12.2 ms, with an average fall time of 4.1 ms.

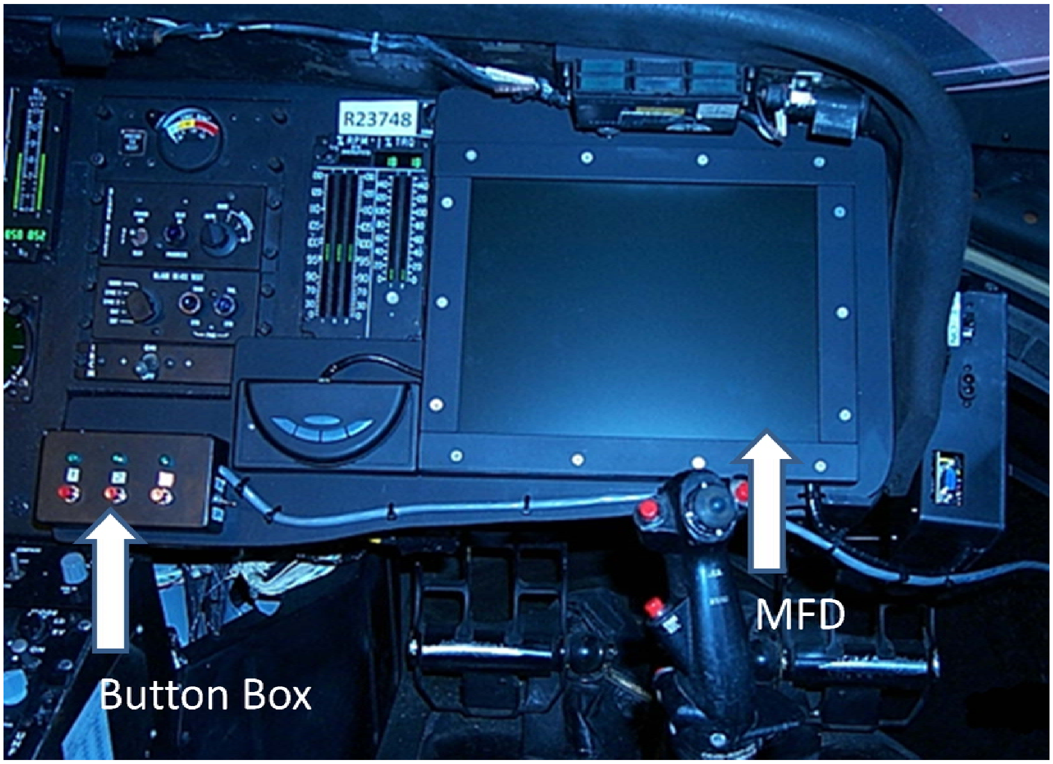

Figure 2. Modified cockpit configuration of the USAARL flight simulator.

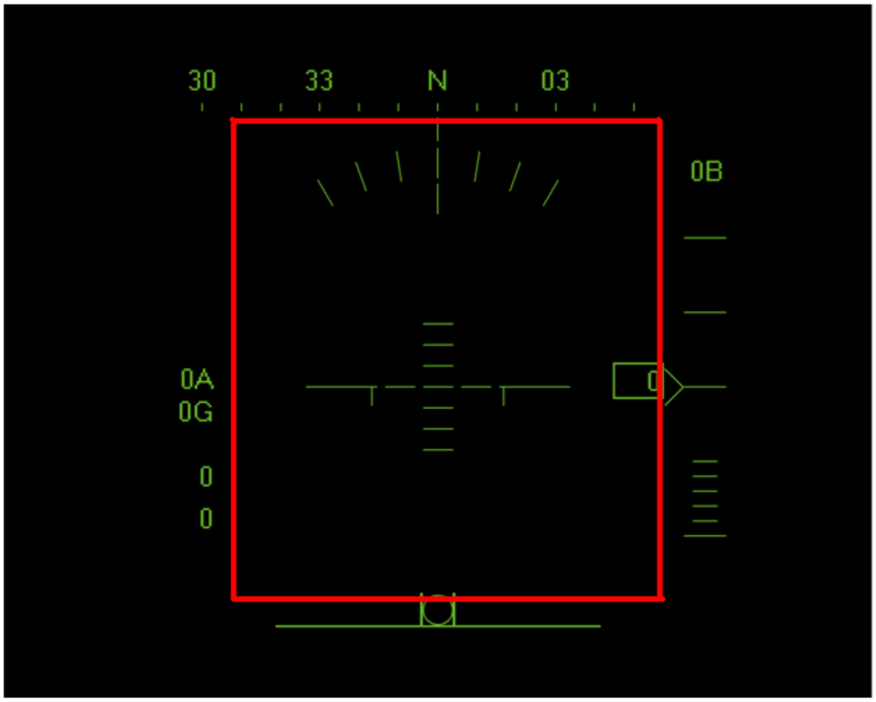

Figure 3. Picture of the MFD used in the study. The gray thick lined box (which was not present during the study) shows the region in which the cue presentations were made.

Button box

A button box was created to collect pilots' reaction time to presentation of each subthreshold cue (figure 2). The button box was located on the far left of the panel and within reach of the hand used to operate the collective. The button box consisted of three buttons each designating a different response. Above each button was a letter (C, W, and X from left to right for all trials) to remind the subject of the button assignment, and above each letter was a green light which turned on when any of the buttons were pressed. This button box was linked to the computer used for the flight data collection and indicated the pilot's reaction times and identification of any buttons that were pressed.

Procedure

Survey administration

Following the informed consent, subjects filled out the demographics questionnaire (appendix A), and then were briefed on their mission (appendix B) and flight profile (appendix C). Each subject was provided a copy of the mission to read while the researcher briefed the mission aloud. Following the briefing, subjects were then introduced to the research pilot and technician with whom they would fly the flight simulator. Upon completing the mission, the subject exited the simulator and completed the post-flight questionnaire (appendix D).

Flight task

Since the subjects were not familiar with the MFD used in the study, they were given a 10-minute familiarization period in which they could fly in the simulator and ask any questions pertaining to the MFD and the forthcoming mission. Once the research flight started, the subject was reminded of the task and then lifted-off toward the first waypoint. When subjects reached each waypoint, the research pilot informed them of the new heading, above ground altitude, and ground speed they were to maintain. If the pilot deviated from these measurements more than Army standards permit (±100 feet for altitude, ±10 knots for air speed, and ±10 degrees for heading) for too long (over half a minute without attempting to correct), the research pilot would remind them of their task parameters for the waypoint.

Cue detection task

Subjects were informed that at times during their mission the presentation of a "C," "W," or "X" would appear on the MFD screen. Each letter was assigned to a certain condition of tail boom stress level and required a different pilot response per the mission briefing.[1] Subjects were instructed to press the matching button on the box as soon as they detected a cue so that a measurement of reaction time could be made. Letters were presented in six counterbalanced orders at pre-determined times based on the starting time of the mission (table 1). This assured that each subject within a specific order would receive the cues at the same time, but did not guarantee they would receive the cues at the same points on the map due to variables in flight performances. Cue presentations were limited to 2 minutes and any cues not detected within that timeframe were considered as errors.

Table 5.
Order and timing of cue presentations.

10-minute Block	Every 1st Subject	Every 2nd Subject	Every 3rd Subject	Every 4th Subject	Every 5th Subject	Every 6th Subject
1	+C (2)	- X (6)	- W (7)	+X (6)	+W (2)	+C (8)
2	-W (8)	- C (5)	- X (4)	-W (4)	-C (3)	+X (2)
3	-X (3)	+ W (4)	- C (6)	+C (7)	+X (8)	+W (5)
4	+C (7)	+ X (8)	+W (5)	-X (3)	+W (4)	-C (6)
5	-W (4)	- C (3)	+ X (2)	-W (8)	-C (5)	-X (4)
6	+X (6)	+W (2)	+ C (8)	+C (2)	-X (6)	-W (7)

Note: The minus sign (-) designates a subthreshold (16 ms) presentation. The plus sign (+) designates a suprathreshold (500 ms) presentation. The number located within the parenthesis designates the minute of the 10-minute block during which the stimulus was presented.

[1] A "C" indicated caution, and required the pilot to report the incident, whereas a "W" indicated warning, and the aircraft should be landed as soon as practicable. An "X" indicated danger, and the aircraft should be landed as soon as possible. The pilot did not need to report the incidents or land the aircraft, they only needed to press the matching button on the button box and indicate to the research copilot what they would do if they were to actually respond to the cue.

The manner in which the cues were presented to the subject was a concern of high importance for this study. Pilots constantly shift their attention from one source to another during a flight, so it would not be practical to present the traditional one cue presentation and expect the pilot to detect the cue at all times. In order to address this, the cue would have to repeat over time similar to what was done in the Hewett et al. (2009) study. However, it was not desired to have a cyclic presentation of information as used in Hewett et al. This cyclic presentation induced a new scanning source that became incorporated into the pilot's behavior, thus taking resources away from the processing of other visual information. The researchers decided that a brief unmasked cue would be presented within the MFD. This presentation was for a brief period (approximately 16ms). The location of the cue was presented in the limited range of the MFD, indicated by the gray boxed in area (not seen during the study) presented in figure 3. The location was randomly located with the exception that it was not presented in an already inhabited pixilated location (this avoided possible occlusions or ambiguities of the cue presentation). The cue was presented every 3.5 seconds so that subjects would not see constant presentations of cues and thus prevented the development of a strategy where pilots searched the MFD until they recognized the presented cue.

Previous research claims that for visual presentations to truly be at the subthreshold level they must be presented for 50 ms or less and immediately masked after presentation. However, in this task, masking the cue would lead to a longer stimulus presence thus alerting subjects that a cue occurred. Once alerted, subjects would then likely focus on the MFD until they were able to process the cue. This behavior was not desired because pilots would begin to devote attention to the cueing, which would defeat the purpose of the presentation. In addition, unlike other subthreshold cue presentations, the task here did not have subjects focusing their attention at the location of the subthreshold cue. A typical subthreshold cue presentation requires the subject to focus visual attention to the location in which the cue would be presented. In our study, the cue was presented randomly within a fixed region of the MFD. This made it unlikely that the pilot would focus their visual attention at the location of the subthreshold cue. For these two reasons, it was decided that masking the presentation would not be desirable for this task.

Results

Accuracy

Accuracy was determined by 1) whether the subject correctly identified the cue and 2) pressing the corresponding button on the button box before the presentations ended. A within-subjects *t*-test was conducted on the accuracy rates for subthreshold cues (mean 0.98 correct) and suprathreshold cues (mean 0.94 correct), and found that accuracy was not significantly different between the two groups (p = 0.326, two tailed). Table 6 shows the frequencies of the types of errors made during the experiment. An important note here is that during four of the five suprathreshold incorrect responses, pilots 'verbally' reported the correct response when they described what action should take place, and thus had pressed the wrong button. Note, only one occurrence of a button press without presentation of a cue occurred in our study.

Table 6.
Frequency of error types throughout the entire study.

Error Type	Presentation	Frequency (90 Total Presentations)	Percentage of Total Trials
Undetected Cues	Subthreshold	3	3.3 %
	Suprathreshold	0	0 %
Incorrect Responses	Subthreshold	0	0 %
	Suprathreshold	5	5.6 %
Total Errors	Subthreshold	3	3.3 %
	Suprathreshold	5	5.6 %

Reaction time

Reaction time was determined by measuring the timing difference from when the first cue was presented on the MFD and when the subject responded by pressing the correct button on the box. Incorrect responses on this task were not included in the reaction time analysis, nor were undetected cues. A within-subjects *t*-test was conducted on the reaction times for subthreshold cues and for suprathreshold cues (see figure 5 for means), and found a significant difference between the two groups ($t(29) = 2.201$, $p = 0.036$, two tailed).

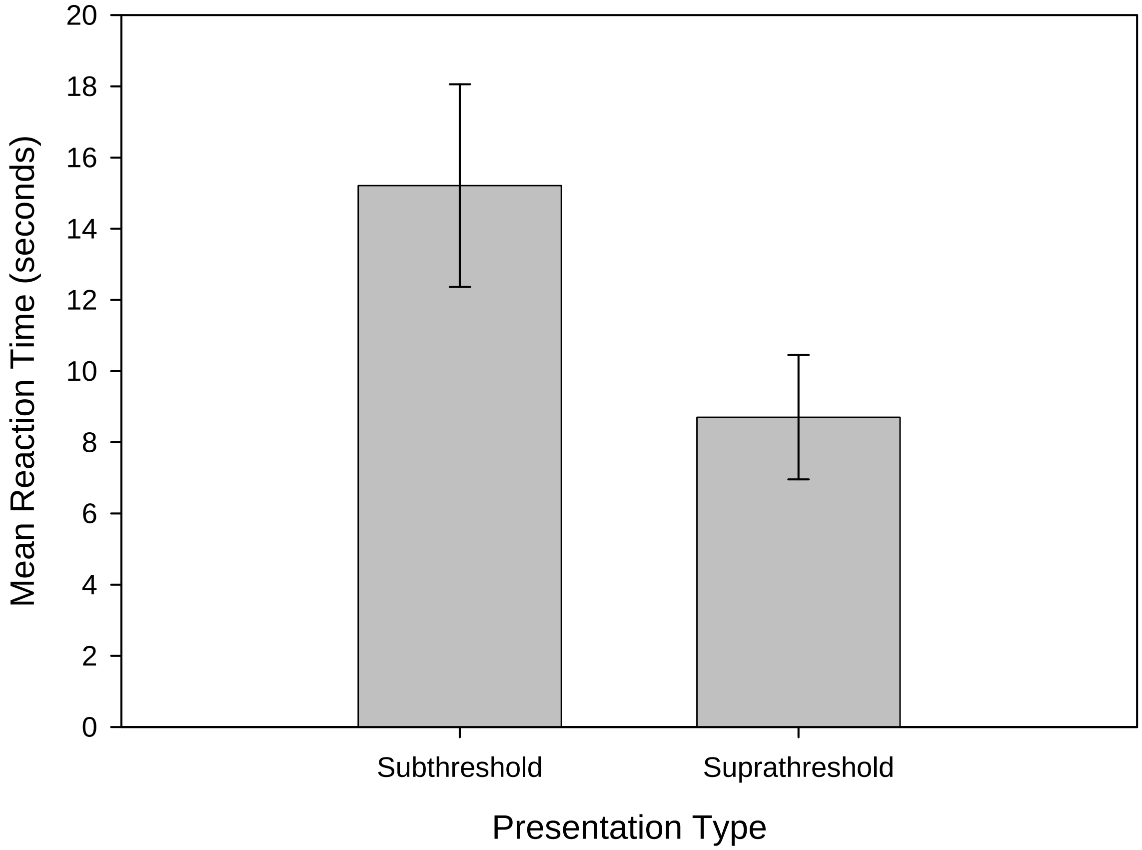

Figure 4. Mean reaction time by cue.

Flight performance and cue detection

As discussed earlier, three measurements were used for flight performance: heading direction, ground speed, and radar altitude. All measurements were converted to mean error differences of the actual flight data and the desired flight criteria. Since the secondary goal of this project was to establish if the visual presentations were a distraction to the pilot, average flight performance for the minute prior to a cue presentation was compared to the average flight performance during cue presentation, and also the average flight performance for the minute following cue presentation response.[2] The reasoning for this type of analysis was that if the results suggested that deviations significantly increased during or following cue presentations, then it could be assumed that the presentation and response to the cue resulted in decreased flight performance.

[2] Since the flight path required turns which typically changed all desired flight goals, measurements were not included in analysis if a turn occurred during the cue presentation (this eliminated 36 trials from this analysis, but never more than one of each cue type per participant). Additionally, if a turn occurred within 1 minute prior to a cue presentation or 1 minute post cue presentation, the average flight performance was calculated for the time separating the turn to cue presentation.

A 2 x 3 repeated measures analysis of variance (ANOVA) was conducted for each of the three measurements recorded to determine flight performance. The conditions were the cue type (subthreshold and suprathreshold) and presentation period (the minute prior to the cue [pre-cue], the time of cue presentation [cue], and the minute following response to the cue [post-cue]).

Heading direction maintenance

The ANOVA results for heading direction (figure 5 for means) determined that no significant differences existed for cue type ($p = 0.220$), between the presentation period measured ($p = 0.283$), or in the interaction between the two measures ($p = 0.348$). The results of the ANOVA suggest that cue type did not significantly influence performance for this flight task.

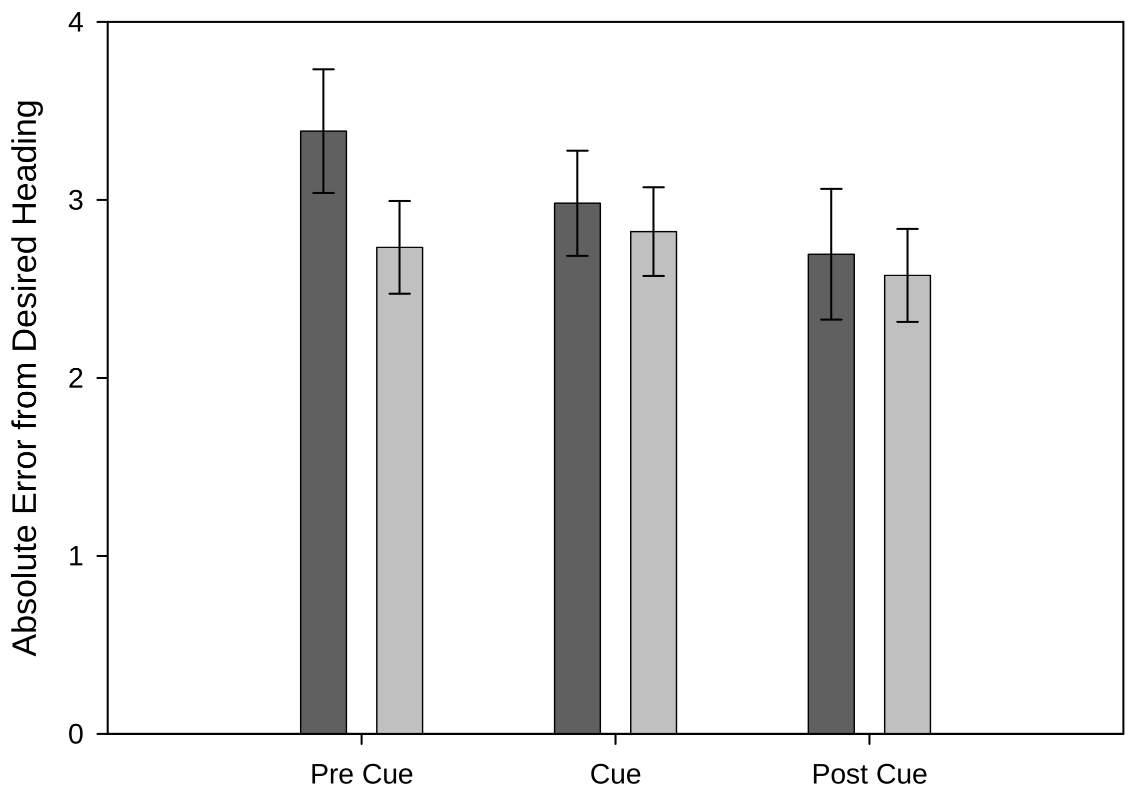

Figure 5. Heading error for pre-cue, cue, and post-cue presentations. Black bars represent subthreshold presentations, while gray bars represent suprathreshold presentations.

Ground speed maintenance

The ANOVA results for speed maintenance (see figure 6 for means) determined significant differences existed for cue type ($F(1, 29) = 6.054$, $p = 0.020$), presentation periods ($F(2, 58) = 11.205$, $p < 0.001$), and the interaction between the two measurements ($F(2, 58) = 10.462$, $p < 0.001$). Post hoc Bonferroni corrected pairwise comparisons were conducted for the presentation

periods and interaction differences. Concerning the presentation periods, the pairwise comparisons determined the flight performance for the pre-cue presentation resulted in a significantly larger flight error than during cue and post-cue presentations (p = 0.02 and p = 0.002, respectively). The interactions were all driven by the pre-cue suprathreshold presentation, which was found to have significantly larger error than all other conditions at the p = 0.05 level.

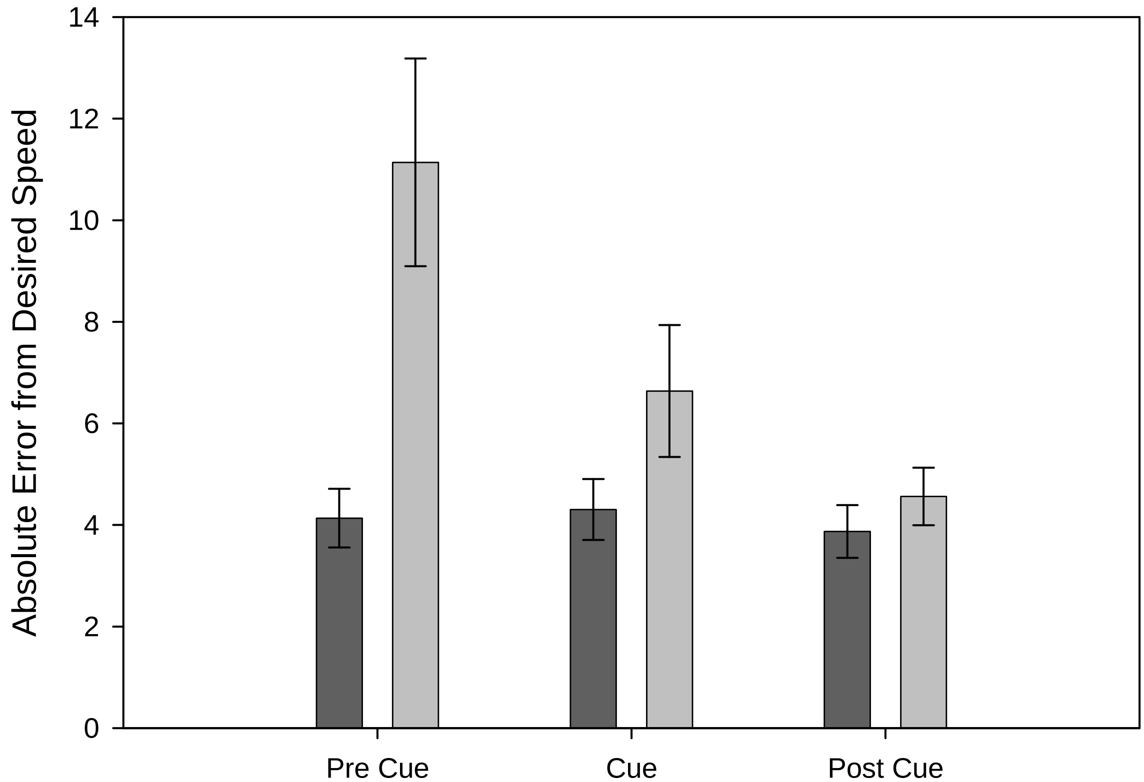

Figure 6. Speed error for pre cue, cue, and post cue presentations. Black bars represent subthreshold presentations, while gray bars represent suprathreshold presentations.

Altitude maintenance

The ANOVA results for the altitude maintenance (see figure 7 for means) determined significant differences for cue type (F(1, 29) = 7.601, p = 0.010) and for the interaction between the two measurements (F(2, 58) = 4.303, p = 0.018), but not for the presentation periods (p = 0.742). Post hoc Bonferroni corrected pairwise comparisons were conducted to determine which interactions were significantly different. The results suggested that the pre-cue subthreshold condition was significantly different from all suprathreshold presentation conditions, and that the cue subthreshold condition was significantly different from the post-cue suprathreshold condition (all significant at the p = 0.05 level).

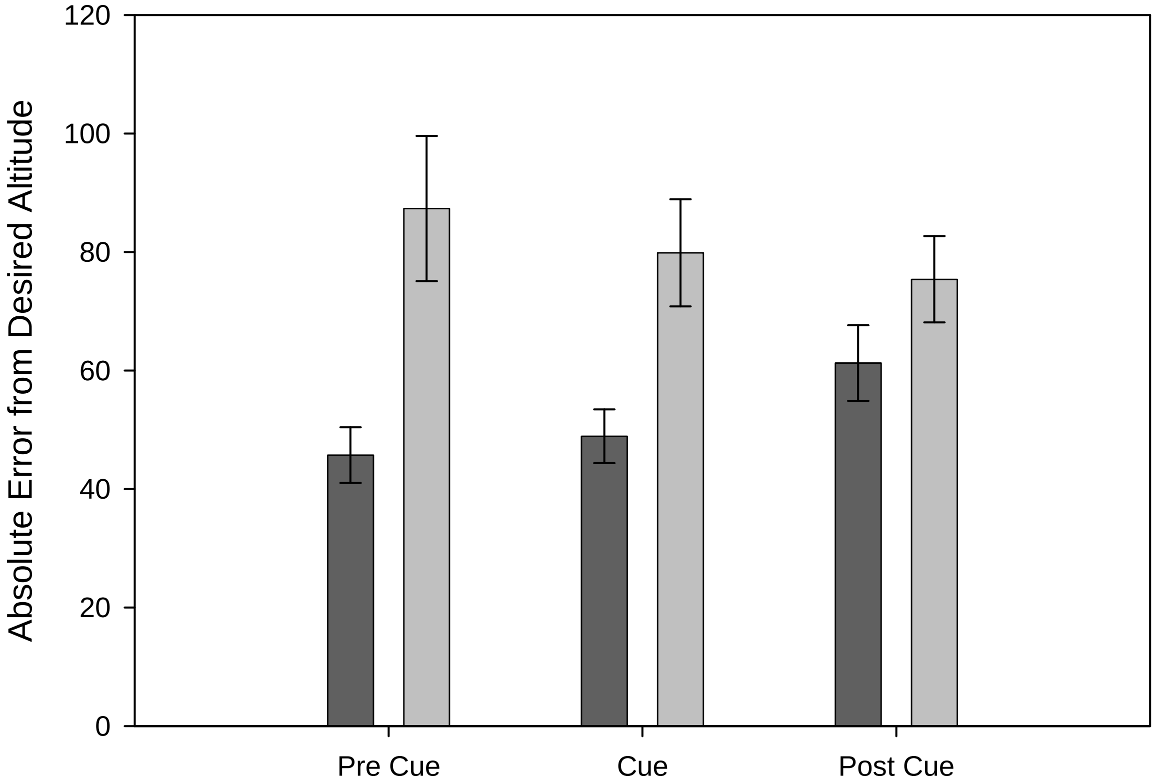

Figure 7. Altitude error for pre cue, cue, and post cue presentations. Black bars represent subthreshold presentations, while gray bars represent suprathreshold presentations.

Cue response over time

During the design of the study it was unknown if pilots would have poorer performance in cue detection during the beginning of their flight due to the novelty of the task, or if pilots would get worse as the study progressed due to a lack of interest or possible fatigue. Visual observations made by the primary researcher suggested that a clear majority of the longer reaction times occurred during the beginning portions of the study. In order to determine if time influenced performance, a correlation of each response for the two cueing conditions was created with groupings of the block of time in which the cue was presented. Only correct cue detections were used in the analysis.

Tests determined a significant correlation existed for the subthreshold presentations ($r(87) = -0.408$, $p < 0.001$, two tailed) but not for suprathreshold ($p = 0.125$, two tailed) presentations across time (figures 8 and 9 respectively). Results suggest that pilots gained familiarization with the task after early exposures.

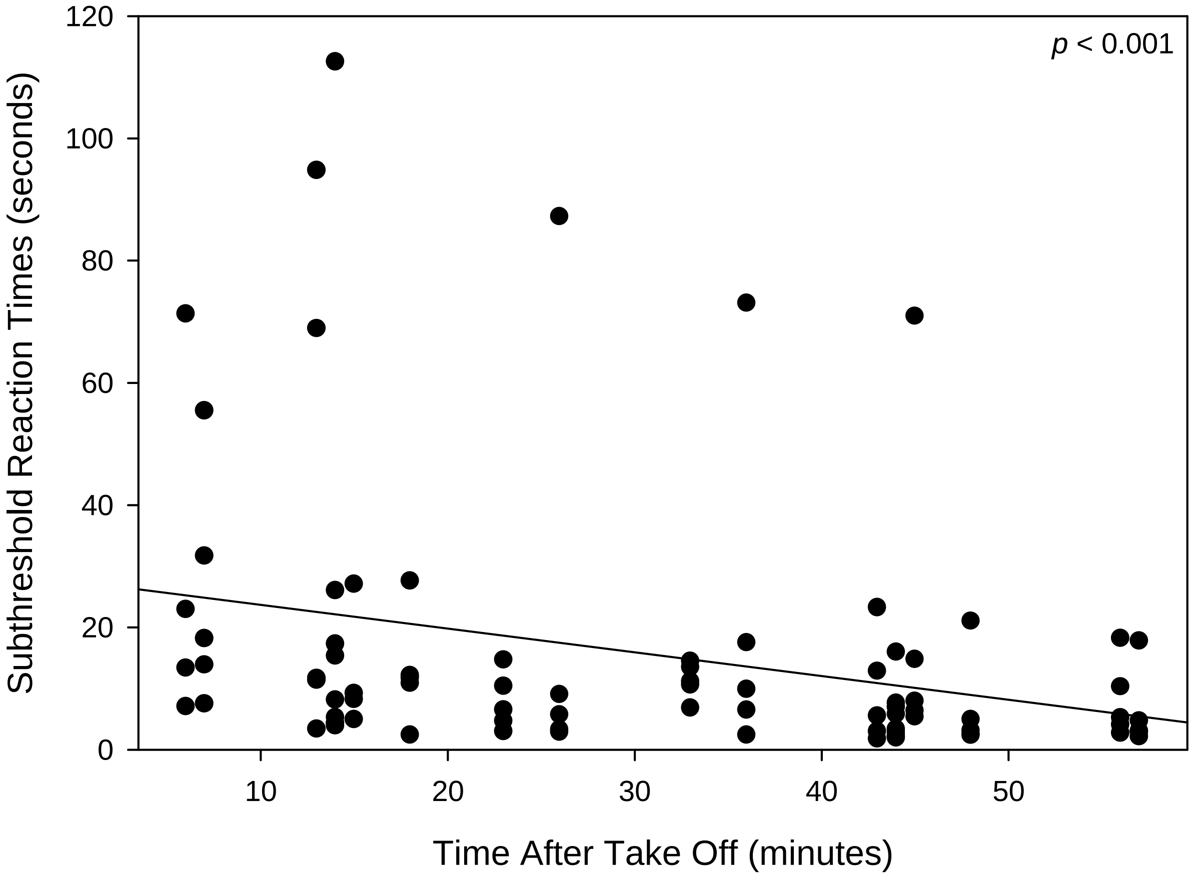

Figure 8. Presentation blocks correlation with subthreshold cue response time.

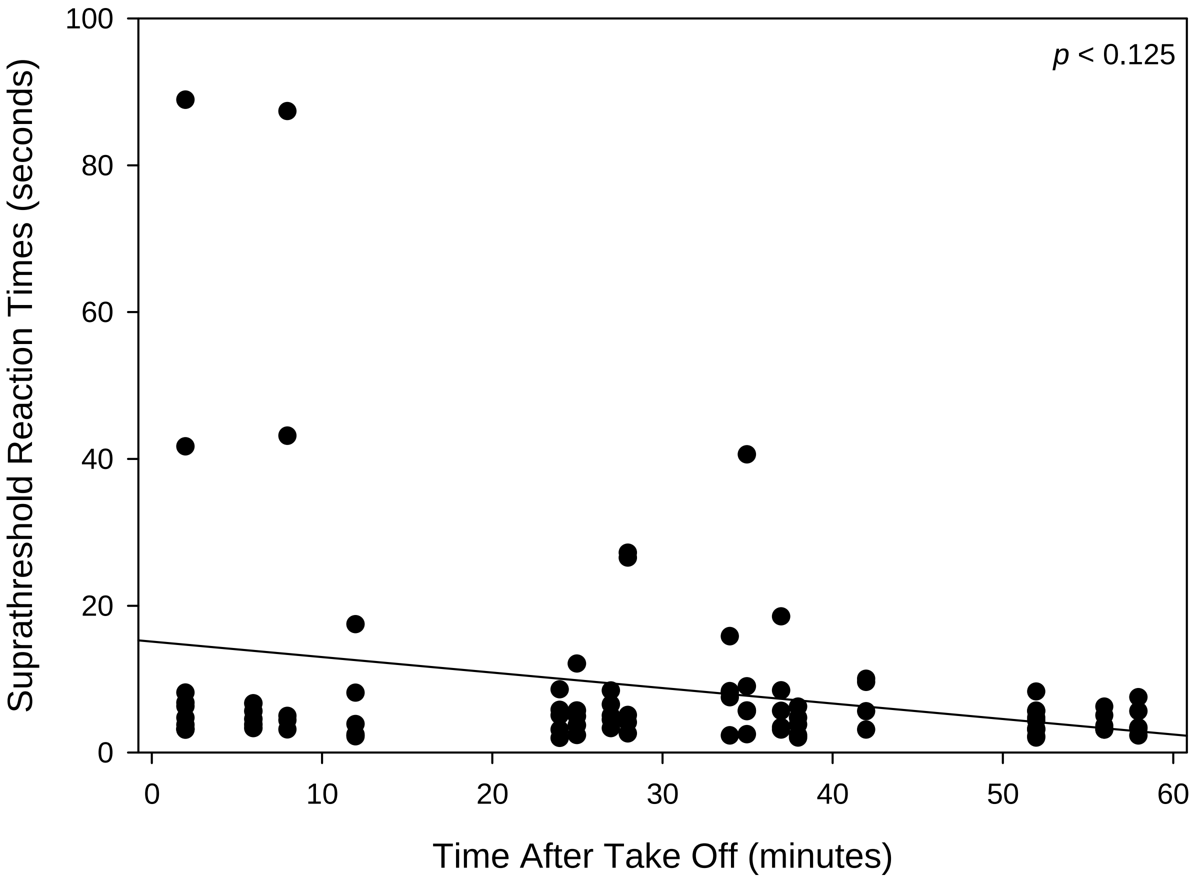

Figure 9. Presentation blocks correlation with suprathreshold cue response time.

Post-flight questionnaire

The post-flight questionnaire allowed subjects to give feedback concerning their experiences of the study. The descriptive results of the survey are provided in tables 7 through 13. Highlights of the descriptive results suggest that a majority of the pilots were motivated by the MFD alone to indicate a response to the tail boom stress (90%, table 7), and that a majority of individuals were not distracted by the cue detection task (73.3%, table 12). Overall, surveys trended toward positive results for the usage of subthreshold cues to relay information concerning events during flight. However, results were not always clearly in favor of the cue's use (tables 10 and 11), suggesting that pilots may need more experience with the presentation or that further steps are needed to perfect the presentation of subthreshold cueing.

Table 7.
Describe the feeling that motivated you to check the tail boom button?

	Urgency	Fear of crashing	Other
Frequency (%)	15 (50%)	0 (0%)	15 (50%)[3]

Table 8.
When you checked the tail boom button, were you motivated by the Multifunction Display or purely by chance?

	MFD	Chance	Neither	Both	Other
Frequency (%)	27 (90%)	0 (0%)	0 (0%)	3 (10%)	0 (0%)

Table 9.
Has participating in this experiment influenced your opinion of subthreshold priming/ subliminal messaging?

	Yes	No	Other
Frequency (%)	15 (50%)	11 (26.7%)	4 (13.3%)[4]

Table 10.
After completing this experiment, do you have a positive or negative view of subthreshold priming/ subliminal messaging?

	Positive	Negative	Other
Frequency (%)	14 (46.7%)	8 (26.7%)	8 (26.7%)[5]

Table 11.
In your opinion, do you think subthreshold cues could benefit the cognitively overloaded aviator?

	Yes	No	Other
Frequency (%)	15 (50%)	10 (33.3%)[6]	5 (16.7%)[7]

[3] All comments here suggested subjects were motivated by the instructions they were given.
[4] Three comments suggested the subjects were unsure and would like to see more information pertaining to the topic, while one subject said they were interested in the simulated malfunctions of the task.
[5] Seven comments suggested that subjects were neutral in their opinion toward cueing while one suggested they preferred a steady indication that did not change location.
[6] One subject reported that the cueing caused second guessing of what they were seeing.
[7] All subjects reported the cueing was too unfamiliar for them to decide on at this time and with more experience it may or may not be useful.

Table 12.
Were the subthreshold cues a distraction?

	Yes	No	Other
Frequency (%)	3 (10%)	22 (73.3%)	5 (16.7%)[8]

Table 13.
Were you worried or distracted about this additional task?

	Yes	No	Other
Frequency (%)	7 (23.3%)	20 (66.7%)	3 (10%)[9]

Discussion

The results suggest that pilots were able to successfully distinguish subthreshold cues just as well as they were able to distinguish suprathreshold cues. The lack of a difference found between distinguishing the two types of presentations suggests that pilots were able to process the extremely brief visual presentations and utilize the cues for flight information. This finding is important as an early step in evaluating the usage of subthreshold cue presentation as a valid source of visual input in an oversaturated visual environment. The overall high accuracy rate suggests that the pilots in this study could distinguish the cues when presented. However, the reason for the ease of distinguishing the cues is not clear. One possibility is that without the mask, the presented cues were easily distinguished and were processed at the conscious level. This would explain the results and demonstrate the similar accuracy between the sub- and suprathreshold presentations. Another possibility is that since cues were presented multiple times, pilots may have detected a presentation on the MFD and then fixated on the MFD until they were able to discriminate the cue type. Since they knew the cue would be presented multiple times, a pilot could wait study the MFD until they were sure of the correct response.

It should be noted that the time to process the visual information of the subthreshold cues was significantly slower than the time to process suprathreshold cues (figure 5), suggesting that subthreshold cues are not the type of cueing that would best suit situations requiring immediate action (subthreshold cues were responded to in 15.21 seconds on average, while suprathreshold cues were responded to in 8.7 seconds on average). The significant 6-second difference between detection times suggests that subthreshold cues were more difficult to process than the suprathreshold cues. However, it is unknown if the difference between the two types of presentation differed on detection, discrimination, or both. Difficulties in either would lead to negative differences in reaction times, but for different reasons. If subthreshold presentations were more difficult to detect, then multiple presentations would be necessary before pilots processed the information. However, if subthreshold presentations were more difficult to

[8] One subject report it was difficult to distinguish which letter was presented, while the other four subjects indicated that they were looking more inside of the helicopter and within the MFD for the signals than they typically would during the flight.
[9] All three subjects reported that they focused on the MFD and were concerned they would miss the cue.

discriminate, then a pilot would initially detect that a cue had been presented, but would not be able to distinguish the cue due to the short presentation. Discrimination could be possible by waiting for the repeats of presentation until the pilot was sure of the cue from other possibilities. Possible evidence that may suggest that a pilot was able to detect and discriminate subthreshold cues without repeated exposure is that 16 of our subjects responded to at least one subthreshold cue prior to 3.5 seconds (the time required for a second presentation), with five of those subjects having multiple subthreshold cues responded to in under 3.5 seconds. It is possible, but unlikely; that all of these responses were on trials in which the cue's location was within the pilot's visually attended to area.

The analysis of the flight data suggests that flight performance (as measured by our three conditions) slightly improved during and following cue presentation, but it is important to stress the small amount of difference here and that for a majority of the time each pilot was within Army flight standards. The fact that flight performance was not negatively influenced by both cue type presentations further suggests the validity of our cue presentations. A pilot must be able to process several components of information via his or her scanning behavior, thus demanding that attention is shifted from one area to another in an orderly fashion. Failure to do this could lead to neglecting one or several sources of information, and a loss of SA. Presentation of non-critical information in a non-attentional demanding way should allow a pilot to process information without sacrificing SA.

When the cue presentations were viewed chronologically, the data showed that pilots detected the cues faster over time. This could suggest that, at first, pilots were unsure of what to look for on the MFD, or that they improved at detection of the cues over time. Either way, the pilots quickly learned the task and were able to process the information with little or no hindrance as the post-study survey suggests. The relatively quick learning suggests that this presentation of information takes little practice to master.

Survey results do not clearly suggest our pilots support the use of subthreshold stimuli with only 50% responding that this mode of presentation would benefit pilots, but the overall comments were not altogether negative. A few pilots expressed that they were too unfamiliar with this form of visual presentation, so it may be interesting to see how pilots respond after more exposure (or training) to this means of presenting information. A majority (73%) reported that the presentations were not a distraction. This finding suggests that subthreshold cues are a way of presenting visual information without taking attention away from other areas of focus.

Study limitations

Although the results of the study are encouraging, the overall reaction time for the pilots to respond to either cue type needs to be further investigated. Obviously pilots had to be attending to the MFD during cue presentation in order to detect and process the cue. Without tracking the eye movements of the pilots, it is unknown if reaction times were extended due to 1) attention being directed to other regions, or 2) the pilots typically requiring multiple presentations to process the cues.

The importance of the distinction between the two possibilities is that a delay due to where the pilot was attending would suggest that subthreshold cues could be processed at a faster rate. This faster rate may allow more important information to be processed than we previously thought. The key would be to find a way to present the cues that is not hindered by where the pilots are looking. This could be resolved by presenting the cues via a helmet-mounted display. However, if the cues are not always processed while pilots are attending to the MFD, then this would limit the type of information that should be presented by subthreshold cues. Important emergency or urgent information should not be presented in subthreshold format. Reminders and other non-critical information though would be acceptable in this format.

Conclusions

The idea of presenting information to pilots in a format that does not require additional attention or cognitive resources to process may be an effective means of presenting additional information to pilots in an already over stimulated environment. The results of this experiment suggest that pilots can process briefly presented stimuli, and that the stimuli were not a distraction to the task of operating the helicopter. Our results suggest that research into subthreshold cues may be promising and could lead to gains of SA without a loss of attention. Future studies should focus on determining the type of information that would benefit most from this form of presentation, and the best way to present this visual information to pilots.

The type of information that could be represented in the subthreshold format would appear to be very basic and not of critical importance. The presentation of this information must also address that pilots are constantly shifting attention from one region to another, and by limiting this information to one area, as our study did, could lead to pilots missing information or processing it at a later time due to where the attention was during cue presentation. Overall, the findings suggest that subthreshold cues can be processed during cognitively demanding tasks and can be used to present non-critical information to a pilot without sacrificing pilot performance.

It is unknown if our presentation time, frequency, and location are optimal for presenting information. Shorter durations may be processed just as well with less frequent presentations if they are presented consistently within the visual field of the individual (as would be presented via a helmet visor display). Additionally, pilots may not be the only individuals or Soldiers who may benefit from this technology. Both military and commercial drivers are tasked with similar environments, and even individuals working on computers may benefit from non distracting reminders of other tasks or meetings in the near future. This study confirms that subthreshold presentations can be used in a real life environment, but further research will be needed to determine their full benefits.

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Appendix A.

Demographics questionnaire.

Participant # _______

Please provide the following basic information regarding your aviation experience. All responses are confidential. The data collected will be used for research purposes only.

1. Age:____________ 2. Sex: Male Female

3. Rank:___________ 4. Unit:__________

5. Date of Flight School Graduation (month/year):_______

6. How many total flight hours have you logged (exclude simulator)?

1-500 501-1000 1001-1500 1501-2000 2001-2500 2501-3000

3001-3500 3501-4000 4001 or greater

7. How many total simulator hours have you logged?

1-25 26-50 51-75 76-100 101-125 126-150

151-175 176-200 300 or greater

8. Please list all type and model aircraft in which you are qualified:

9. Job title:

Pilot in Command Line Pilot Instructor Pilot

10. What is your current Flight Activity Category (FAC) designation?

1 2 3 NA

11. What is your current Readiness Level (RL)?

1 2 3 NA

Appendix B.

Pre-flight brief.

You have been assigned to fly a VFR mission from NAWS China Lake, CA, to Furnace Creek Airstrip, CA, via a predetermined route (see route card) in which you will be transporting precious cargo for the National Command Authority (NCA). Your mission will take approximately 1 hour and is critically important to national security. You have been chosen for this mission based on your precision flying ability. You will be flying a UH-60 Black Hawk which has been uniquely configured with a multifunction display (MFD) on the right side which provides digital flight information. Due to airspace de-confliction and national security reasons, you must fly the mission precisely as detailed on the waypoint card. You will be accompanied by a copilot who will serve as your navigator. The weather for the mission (ETA + 1 hour) is clear, with 15 statute miles of visibility, and calm winds.

In addition, the aircraft is equipped with a tail boom stress detection system (SDS) and a novel system that provides either suprathreshold (overt) or subthreshold (subliminal) alerts via the MFD when a condition of tail boom stress or damage is detected. The alerts are characterized by the letters C, W, and X.

An illuminated “C” indicates “caution” that the SDS has detected that the stress on the tail boom has exceeded an established limit. An entry is to be made on the DA Form 2408-13 at the completion of the flight. A “W” indicates a “warning” that the tail boom has received sufficient stress to cause a crack and the aircraft should be landed as soon as practicable. An “X” indicates that a possible crack has been detected and that the aircraft should be landed as soon as possible for a visual inspection by the crew chief. After perceiving the alert, you must push the appropriate button, verify the condition (illuminated light), and decide how to proceed/modify the mission.

Appendix C.

Flight profile.

WPT #	DESCRIPTION/ NAME	HDG	NM	ALT	TIME	GROUND SPEED
	NAWS CHINA LAKE AIRFIELD N35 41.00 W117 42.51				**TOTAL 55+36**	
1	**FIGURE 8 ROAD N35 40.74 W117 20.95**	**096**	**17.5**	**500 AGL**	**8+35**	**130**
2	**ROAD / DRY RIVER INTERSECTION N35 58.74 W117 20.76**	**007**	**18.0**	**500 AGL**	**8+18**	**130**
3	**NONDESCRIPT TURN POINT N35 59.48 W117 15.13**	**087**	**4.6**	**500 AGL**	**2+07**	**130**
4	**TWO VALLEY INTERSECTION N35 43.73 W117 05.89**	**161**	**17.4**	**350 AGL**	**8+39**	**120**
5	**LAVA PATCH N35 56.38 W116 44.15**	**061**	**21.7**	**450 AGL**	**10+03**	**130**
6	**SATELLITE DISH N36 07.93 W116 48.96**	**348**	**12.2**	**300 AGL**	**5+39**	**130**
7	**ROAD / DRY RIVER INTERSECTION N36 20.63 W116 51.88**	**356**	**12.9**	**250 AGL**	**6+27**	**120**
8	**FURNACE CREEK AIRSTRIP N36 27.41 W116 52.69**	**001**	**6.8**	**150 AGL**	**5+36**	**80**

Appendix D.

Post-flight questionnaire.

Participant # _______

1. Describe the feeling that motivated you to check the tail boom button?
   a. Urgency b. Fear of crashing c. Other (please explain) ______________________

2. When you checked the tail boom button, were you motivated by the Multi Function Display or purely by chance?
   a. MFD b. Chance c. Neither d. Both
   e. Other (please explain) ____

3. Has participation in this experiment influenced your opinion of subthreshold priming/ subliminal messaging?
   a. Yes b. No
   c. Other (please explain) ____

4. After completing this experiment, do you have a positive or negative view of subthreshold priming/ subliminal messaging?
   a. Positive b. Negative
   c. Other (please explain) ____

5. In your opinion, do you think subthreshold cues could benefit the cognitively overloaded aviator?
   a. Yes b. No
   c. Other (please explain) ____

6. Were the subthreshold cues a distraction?
   a. Yes b. No
   c. Other (please explain) ____

7. Were you worried or distracted about this additional task?
   a. Yes b. No
   c. Other (please explain) ____

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